The wire leading from the collector should be nailed to the lower end of the collector and soldered thereto. The wires leading to the coherer—about one foot on each side—should be flexible, so that they will not interfere with the movements of the decoherer. The decoherer should be tilted to one side—the side away from the hammer. As there is a small current passing through the coherer constantly, sooner or later it will "stick"—that is, refuse to work. Therefore it should be given a rest as often as possible by cutting it out or putting in one of the extras. Sometimes the decoherer bell will ring once and sometimes it will ring several times, according to the intensity of the lightning discharges. Closed-circuit batteries will last longer than open-circuit ones.

Dr. Lee DeForest, of the American DeForest Wireless Telegraph Company, during a recent visit to New Orleans, suggested to the writer the advisability of thoroughly insulating the coherer wires from the walls of the building.

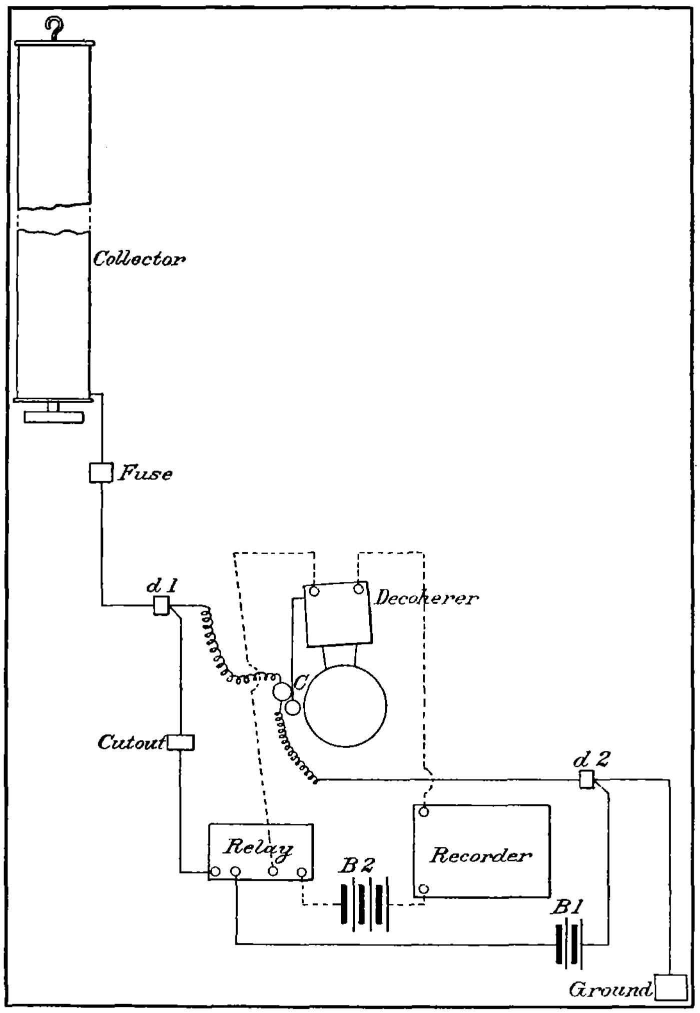

FIG. 2.—Diagram of the lightning recorder at New Orleans, La. *d*, double connector; *B*, battery; *C*, coherer.

Summarizing the results obtained so far it may be said that:

1. A practical lightning recorder can be made at small cost that will give results fully warranting the cost of construction.

2. Where written signals are not required, the bell on the decoherer can be utilized for giving audible signals; and the cost of the apparatus greatly reduced.

3. The recorder will not tick merely because the sky is cloudy and threatening; in cloudy weather it will give signals only when barometric and other atmospheric conditions favor the formation of thunderstorms. In storms coming from a great distance signals were recorded with a clear sky.

4. In most cases, frequent signals in the early forenoon indicate that a thunderstorm will occur later in the day. In some of the thunderstorms of which we have obtained records, the first peal of thunder heard at station was preceded by an hundred or more signals.

5. The collector described above is not an element of danger to the station. It will not attract lightning any more than an ordinary smokestack similarly exposed.

6. The cost of operating the lightning recorder need not exceed that of operating two large-sized doorbells.

7. Generally speaking, the higher the collector stands above the ground the larger will be its range of action.

In working out the mechanical details of the recorder the writer received valuable assistance from Mr. F. W. Ax, of the New Orleans office force.

THE INTRODUCTION OF METEOROLOGY INTO THE COURSES OF INSTRUCTION IN MATHEMATICS AND PHYSICS.

By PROF. CLEVELAND ABBE.

[Read November 26, 1904, at Chicago, before the Central Association of Science and Mathematics Teachers.]

The study of meteorology has acquired a new and vivid interest since the establishment of fairly successful weather forecasts in this country and Europe. The civilized world now knows that the weather and the climate, the winds and storms are controlled by rigorous laws of nature. We may not understand these laws as yet, but they are in control of the universe and we are to discover them and utilize them for the benefit of mankind. We have not yet found any limit to the attainments of the human intellect, and what the mind can do in the way of thinking the hand will find some means to attain in the way of doing. We must think out our work before we can do it.

The ultimate object of all your systems of education, elementary, collegiate, and postgraduate, is to train the mind to think and then train the hand to do. In old times the schools crammed the brain with the results of work already done, memorizing a multitude of facts; but now, while not neglecting the memory, we seek to develop the reasoning faculties, or the reasoning habit of thought, and then to perfect our methods of doing. Our schools pay much attention to mathematics, mechanics, chemistry, and science in general, because these have an important practical bearing on our lives. In this new progress, the professional side of education, meteorology has not been neglected altogether. I have been greatly pleased to see the enthusiastic reception accorded it in every part of the Union and its growing popularity in both graded and high schools. I suppose that we owe this specifically to the general success of the Weather Bureau, but more particularly to Prof. Wm. M. Davis, who established a school of meteorology about 1878 as a division of the school of geology at Harvard University. His students and text-books, his "Elementary Meteorology," the "Climatology" of his successor, Prof. R. DeC. Ward, and their methods of teaching have awakened teachers and professors alike to new possibilities. Other schools and other text-books have come into existence and the elements of the subject are now so well provided for that I do not need to say more about this; but I do feel the need of further advances.

I regard meteorology not so much as a matter of observation and generalization as a matter of deductive reason. Our studies have approached the limit of what we are likely to discover by inductive processes. We stand where astronomy stood in the days of La Place. We have had our Galileo and Newton, but we still need other leaders, and you will all agree with me that these must be trained in the schools. They must get their first lessons from you. Twenty or thiry years hence our future masters in meteorology will tell how their feet were turned in the right direction by the teachers of to-day.

In every school I find several boys and girls that have taken a deep interest in the weather and its relations to our lives. They are often asking questions that bear upon it. They appear to observe and understand it better than others. These are they whom I would have you secure for the possible service of the Weather Bureau. There are others that often appear dull, but they are not really so; their previous education has perhaps been imperfect, some one has confused their minds with erroneous ideas, of which they can not easily rid themselves. There are others who have not yet awakened to a full interest in intellectual work. In general the school will be benefited by taking up exact and experimental work as compared with inexact, indefinite, texts or phrases. We benefit a child more than we realize when we give him exercises in exactness. Why do we make him calculate interest to the last cent? Why practise the piano or singing until he can do it properly? Why draw or paint correctly? Why speak English precisely? Is it not our conviction that what is worth doing at all is worth doing well. It is only the things that are well done that tell. Even in morals it is the bad thought that is the first step toward a bad act. So I wish to enforce the idea of teaching meteorology accurately and to do this we must use accurate expressions and experiments, accurate figures and drawings, and correct mathematics. On the other hand we enliven all mathematical and physical courses of instruction if we introduce into them applications to familiar subjects. The dullest student becomes alive as soon as he perceives that his distasteful mathematical tasks will help him to understand some subject that really interests him. There is no one, not even a child, that has not some favorite subject of thought, some one unanswered query, lurking in his brain. Find out what that is and you have found the keynote to which all his education may be made harmonious.

I know that the schools and colleges find so many subjects to teach and that the hours of work are so taken up at school and at home, that you will say, it is out of the question to introduce another new study. However, I do not venture such a presumption, but would suggest a simple and practical scheme. The idea is simple.

When you are teaching mathematics or physics and seeking for examples illustrative of the applications of these subjects, give especial attention to meteorology and take your examples from the phenomena of the atmosphere. You may not at first find many cases; certainly there are very few in the books. You may have to draw upon your own reading and knowledge or upon the notes that you will find in the MONTHLY WEATHER REVIEW. But with a little ingenuity you will soon accumulate a goodly number of problems that will afford your students abundant food for thought.

I find that many take up mathematical physics as one of the courses leading to the various engineering professions because the latter offer them a prospect of a good business for life; but occasionally one of these finds himself interested in the scientific or research aspect of the various problems as much as or even more than in the engineering aspect. He will probably combine research with his business, if, indeed, he does not altogether relinquish the latter for the former, provided a favorable opportunity offers. Such a man is representative of the class from which the ranks of the future army of American scientists will largely be recruited; and if you find any such, you will do well to help them develop their tastes for meteorology. They have studied mechanics, thermodynamics, steam engineering, electrical engineering, hydraulic engineering; they are graduates of our schools of engineering, they have truly the very best foundation for research in meteorology, and their tastes incline in that direction. One can not expect to make any great advance in meteorology without having a broad foundation, an inquiring mind, and great intellectual energy and perseverence. If the colleges and universities are not yet ready to give meteorology an independent place—a professorship, an observatory, a laboratory—as they do for astronomy, chemistry, geology, and many other branches of knowledge, then the best temporary arrangement that we can make is to introduce it freely among the problems illustrative of the general courses in the fundamental mathematical and physical studies of all exact science.

But you will ask for some definite examples.

(1) Among the simpler applications of trigonometry are the various efforts made to determine the altitude and motion of the clouds. The simplest method consists in determining the actual motion of a cloud by observing the perfectly parallel and similar movement of its shadow on the ground. One may stand upon an eminence and survey the landscape and with the help of a good map and the second hand of a watch or a simple seconds pendulum, may determine the direction of motion and the linear velocity of as many shadows as he wishes. If at the same time he looks directly upward and observes the apparent angular velocity of a cloud as it passes the zenith, he will find that he has now the base and one angle of a right-angled triangle, of which the other side is the cloud altitude, which of course can then be computed by trigonometrical tables or still better by geometrical constructions. Trigonometry, geometry, arithmetic, and algebra should all be kept at the finger tips ready for use by young students of science. Often times a young man will stand in front of a theodolite or some other complex apparatus and feel that it is too much for him; others have their heads full of mathematics, but do not know what to do with it. The expert is the man who not only has the knowledge but also the ability to do something with it. Our education should include especially the prompt and practical utilization of every scrap of knowledge that we have fortunately acquired.

(2) Another ingenious application of geometry to the altitude of clouds is known as Feussner's method. An observer stands at O and sees a shadow at K at a spot that he can identify on a detailed map of his surroundings. He recognizes that this shadow is that of a cloud at C that is located in the same vertical plane with the sun itself and he therefore observes the apparent angular altitude of that cloud, which is the angle $C\ O\ K$ in the triangle. Now the angle $C\ K\ O$ is the same as the apparent angular altitude of the sun, since a line drawn from O to the sun would be parallel to the line from K through C to the sun. If, therefore, the observer measures the angle by which the sun is above the horizon, or SOH, he will then know the base $O\ K$ and the two angles at O and K and may compute or construct the vertical height of C above the horizon. There are several refinements to be thought of. K may not be on the same level with O; the cloud may have moved before he can observe its altitude and the sun's altitude after having identified the shadow K as belonging to the cloud C. These refinements offer slight difficulties that may be overcome; thus if one has a correct watch he may simply observe the time when the shadow was at the point K, and from that compute at his leisure the altitude of the sun.

(3) One of the oldest methods of determining the altitude of a cloud is known as Bernoull's. The observer at O sees the cloud at C just as the last ray of the sun illuminates it. This last ray must have grazed the surface of the earth at some point W below the western horizon. By observing the time, we know at once the angle between the radii drawn to the earth's center from O and from W. This gives us the means of computing the distance from W to our vertical. But we also observe the apparent angular altitude of the cloud or the angle between $O\ C$ and the vertical. We have now all the data needed to solve the problem. We have in fact three triangles to solve in succession. The problem becomes more complicated if we endeavor to allow for the refraction of the ray of light from $W\ C$. I will not give the latter complex formula now, but may say that I hope to publish a long series

of these problems in a little handbook for the use of students and teachers, and I think that you will not find them too difficult for most of your students. In fact, text-books on trignometry while giving us many interesting problems suggested by the work of surveyors, navigators, and geodesists, seem to have quite forgotten that the clouds offer us still more fascinating problems.

(4) Some years ago the various weather bureaus of the world agreed upon a year of steady work on the altitudes of clouds. Some observers adopted the strictly trigonometric method of altitudes and azimuths. If a theodolite is placed at A and another one at B, the observers endeavor to sight simultaneously on a cloud at C. If they sight on the same point at the same time and observe the altitudes and azimuths correctly, then it would seem certain that with $A\,B$ as the base line they should be able to compute the linear distance of the cloud C and its altitude. But unfortunately a cloud has considerable size and there is never an absolute certainty that A and B observe the same point. Accordingly there arises a very interesting problem as to what points they have observed. Oftentimes calculations showed that the two lines of sight did not and could not intersect, so that the shortest distance between the two lines would seem to be the proper place for the cloud. You will find all the details of this problem in chance, or the theory of errors, as it is called, in a report by Ekholm and Hagstrom.

(5) During that same year other observers used what is called the photogrammeter or the nephograph, which is simply a photographic camera mounted with altitude and azimuth circles. Photographs are taken of the same cloud simultaneously, and from them we may proceed by two methods, (1) we may measure from the photographic plate the angular bearings of various points in the clouds and determine the distance and dimensions of the whole cloud, or (2) we may proceed graphically, set the photographs up in a frame, reproducing as nearly as possible the original locations of the two cameras, and then, using threads as lines of sight, carve out in the air of the room a small model of the cloud itself. This latter process was, I believe, first carried out in England under the supervision of Prof. G. G. Stokes, the eminent mathematician, who was at that time a member of the Meteorological Council at London. In fact, that council has often included some of England's most famous men, and we are indebted to them for a number of important methods in meteorology.

(6) But perhaps the most fascinating as well as the simplest method of studying the clouds is by means of the nephoscope. This is a very simple instrument—merely a circular mirror held horizontally; you look into it and see the cloud by reflection, which saves the trouble of twisting the neck to an uncomfortable position. The mirror has a graduated circle corresponding to the azimuth circle; its center is marked by a dot or cross line and there are a few concentric circles drawn around that. At one side of the mirror is a light vertical rod holding a little knob, which may be raised or lowered and turned around to any azimuth, so that when one observes a cloud reflected at the center of the mirror he may so adjust the knob as to bring its image also at the center. But the cloud moves away and the observer must then move his eye so as to keep the knob covering the cloud until the knob and cloud disappear together at the edge of the mirror or cross some one of the concentric circles. In this process the knob is the center or intersection of two lines of sight, one from the cloud to the knob in its first position, and again from the cloud to the knob in its second position. The horizontal path described by the intersections of these lines with the face of the mirror is a miniature of the horizontal path described by the cloud in the time required by the images to pass from the center to the rim. We obtain thus the direction of motion of the cloud and a horizontal line that may be converted into the angular zenithal velocity. The prettiest application of this instrument and perhaps the most elegant of all methods of determining the height and velocity of the cloud I have called the kinematic method. The idea is this: If we are in a boat or on a train, our motion is combined with the motion of the cloud. We seem to attribute our motion to the cloud, and the observed line is a resultant movement that you easily obtain by compounding movements or forces by the method of parallelogram of forces. If we move from A to B in the boat with our nephoscope, it is as though the clouds move from B' to A' in the parallel but opposite direction; but if the cloud is actually moving from B' toward X, then the result that we observe is the line $B'\,X'$ as seen from the boat. This apparent regular motion we are to observe first when the boat is going from A to B, and again when the boat is going in some other direction, such as B to C, or even when the boat is stationary, or when the boat directly reverses its movement, which we can most easily accomplish by carrying our nephoscope on a trolley or in a rowboat on a canal. Now, these two observations, together with the known velocities of the boat, give us four known terms in a pair of trigonometric equations, from which, by elimination, we determine the altitude and the actual velocity of the cloud. The most difficult point is to determine the velocity of the boat, and the method is, therefore, best adapted to give accurate results when the nephoscope is being carried by a steady steamer or by a car that is pulled by a cable, going at a perfectly uniform rate of speed in different directions, as, for instance, through the streets of a city.

(7) As another mathematical example, I happen to think just now of the so-called Poisson's equation relating to the behavior of pure dry air when undergoing adiabatic changes. This is given in some works on analytical mechanics and is mentioned in the elementary works on physics. But the good student will appreciate it better if you will give him the demonstration based on fundamental principles, which may be made almost purely mathematical.

When the same ideas are applied to the expansion and contraction of moist air, with its changes from vapor into cloud and snow, we come upon a more complex problem in physics; but even this is so largely a question of pure mathematics that it may be included under that category, and I hope that you will make your scholars familiar with the elegant graphic methods introduced by Hertz, whose paper is fully translated in my "Meteorology of the Earth's Atmosphere," and has been still more beautifully treated by Neuhoff in a German paper of 1901, but not yet translated. Elaborate mathematical tables are given by Professor Bigelow in his "Report on International Cloud Observations."

(8) The elementary text-books on physics often mention the theory of the wet-bulb thermometer and its use in determining the moisture of the atmosphere, but they rarely give any satisfactory explanation of the process by which physicists have deduced the relation between the temperature of the wet bulb and the moisture in the air—that is to say, the rate of evaporation; but the process is not so difficult but that anyone who has studied a little of the law of diffusion can understand it, and, for brevity's sake, I must refer you again to my Meteorological Apparatus and Methods.

[To be continued.]